

METHODS, SYSTEMS, AND COMPUTER PROGRAM PRODUCTS FOR
DETERMINING THE LOCATION OF A MOBILE TERMINAL BASED ON THE
STRENGTHS OF SIGNALS RECEIVED FROM TRANSMITTERS HAVING
KNOWN LOCATIONS

BACKGROUND OF THE INVENTION

The present invention relates to wireless communication technology, and, more particularly, to methods, systems, and computer program products for determining the location of a mobile terminal.

Wireless communication technologies are widely used to provide
5 communications services. For example, cellular mobile telephone systems are used throughout the world to provide telephone voice services. Wireless communications services are also widely used to provide text and other messaging services, such as paging services.

A growing market for the application of wireless communication technologies
10 is the provision of data communication services. For example, wireless mobile data communication systems are now used to provide wireless wide area networking such that mobile users, such as salespeople, maintenance personnel, and the like, may use networked applications. Wireless mobile data communications system may also be used to provide mobile Internet services.

A conventional cellular digital packet data (CDPD) communication system
15 **112** is illustrated in **FIG. 1**. The CDPD system **112** includes a CDPD subscriber device known as a mobile end station (M-ES) **114**. The M-ES **114** and a mobile data base station (MDBS) **116** communicate with each other using a CDPD communication protocol. The MDBS **116** communicates with a mobile data
20 intermediate system (MD-IS) **118**, which provides such functionality as authenticating

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M-ESs to ensure that service is only provided to registered users, managing M-ESs as they move from cell to cell and/or change channels within a single cell, and accounting services. Commonly, the MDBSs 116 communicate with the MD-ISs 118 using a transport layer/network layer stack such as TCP/IP (transport control protocol over Internet protocol), UDP/IP (user datagram protocol over Internet protocol) or TP4/CNLP (transport protocol 4 over connectionless protocol). To provide access to other networks, the MD-IS 118 is connected to a router 122, which routes traffic to private networks 124, the Internet 126, and other CDPD service providers 128. A detailed discussion of CDPD may be found in "Cellular Digital Packet Data Networks," by Budka *et al.*, Bell Labs Technical Journal, Summer 1997, pp. 164 - 181. Other wireless mobile data communication systems include general packet radio system (GPRS), which provides packet data communications for global system for mobile communications (GSM) and other time-division multiple access (TDMA) systems, code division multiple access (CDMA) systems, and universal mobile telecommunications systems (UMTS).

Wireless mobile data communication systems commonly use existing wireless voice communications infrastructure. For example, CDPD services may be provided by retrofitting existing Advanced Mobile Phone System (AMPS) base stations with supplemental hardware that enables these base stations to serve as MDBSs in the CDPD network.

Subscribers of CDPD networks may desire to be able to determine their current location using their M-ESs. In conventional CDPD networks, MDBSs may provide M-ESs with the locations of the cells that they are registered in. Typical cell sizes, however, have a radius of up to 10 miles. Unfortunately, this level of precision may be unsatisfactory to some CDPD network subscribers.

SUMMARY OF THE INVENTION

According to embodiments of the present invention, the location of a mobile terminal is determined by receiving, at the mobile terminal, signals from at least three transmitters whose locations and transmit power levels are known. The strengths of the received signals are measured and then the location of the mobile terminal is determined based on the measured signal strengths and the locations and transmit power levels of the transmitters.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features of the present invention will be more readily understood from the following detailed description of specific embodiments thereof when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a network schematic that illustrates a conventional cellular digital packet data (CDPD) communication network;

FIG. 2 is a network schematic that illustrates a CDPD communication network in accordance with embodiments of the present invention

FIG. 3 is a block diagram that illustrates a mobile terminal in accordance with embodiments of the present invention;

FIG. 4 is a block diagram that illustrates a software architecture for use in mobile terminals in accordance with embodiments of the present invention;

FIG. 5 is a block diagram that illustrates a data processing system in accordance with embodiments of the present invention;

FIG. 6 is a block diagram that illustrates a software architecture for use in data processing systems in accordance with embodiments of the present invention; and

FIG. 7 is a flowchart that illustrates operations for determining the location of a mobile terminal based on the strengths of received signals in accordance with embodiments of the present invention; and

FIG. 8 is a network schematic that illustrates operations for determining the location of a mobile terminal based on the strengths of received signals in accordance with embodiments of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that there is no intent to limit the invention to the particular forms disclosed, but on the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims. Like reference numbers signify like elements throughout the description of the figures.

For purposes of illustration, the present invention is described herein in the context of a cellular digital packet data (CDPD) communication system. It will be understood, however, that the concepts and principles of the present invention are generally applicable to communication networks in which a mobile terminal may receive signals from multiple transmitters whose respective locations and transmit power levels are known.

The present invention may be embodied as systems, methods, and/or computer program products. Accordingly, the present invention may be embodied in hardware and/or in software (including firmware, resident software, micro-code, *etc.*).

Furthermore, the present invention may take the form of a computer program product on a computer-usable or computer-readable storage medium having computer-usable or computer-readable program code embodied in the medium for use by or in connection with an instruction execution system. In the context of this document, a computer-usable or computer-readable medium may be any medium that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

The computer-usable or computer-readable medium may be, for example but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, device, or propagation medium. More specific examples (a nonexhaustive list) of the computer-readable medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, and a portable compact disc read-only memory (CD-ROM). Note that the computer-usable or computer-readable medium could even be paper or another suitable medium upon which the program is printed, as the program can be electronically captured, via, for instance, optical scanning of the paper or other medium, then compiled, interpreted, or otherwise processed in a suitable manner, if necessary, and then stored in a computer memory.

Referring now to **FIG. 2**, an exemplary CDPD communication network **232**, in accordance with embodiments of the present invention, comprises one or more CDPD mobile end stations (M-ESs) that may be embodied as mobile terminals **234a,b**. As used herein, the term "mobile terminal" may include a cellular

radiotelephone with or without a multi-line display; a Personal Communications System (PCS) terminal that may combine a cellular radiotelephone with data processing, facsimile and data communications capabilities; a personal digital assistant (PDA) that can include a radiotelephone, pager, Internet/intranet access, Web browser, organizer, calendar and/or a GPS receiver; and a conventional laptop and/or palmtop receiver or other appliance that includes a radiotelephone transceiver. Mobile terminals may also be referred to as "pervasive computing" devices.

The mobile terminals **234a,b** communicate via a plurality of cells **236a,b,c,d,e** served by mobile data base stations (MDBSs) **238a,b,c,d,e**. A function of the MDBSs **238a,b,c,d,e** is to handle radio communication with the mobile terminals **234a,b**. In this capacity, the MDBSs **238a,b,c,d,e** may function as a relay station for data and voice signals. Although only five cells **236a,b,c,d,e** are shown, a typical CDPD network may include hundreds of cells, and may serve thousands of mobile terminals **234a,b**.

In addition, one or more MDBSs and/or mobile terminals may optionally communicate with a terminal locator data processing system **242** as shown with respect to MDBS **238a** and mobile terminal **234a**. This communication connection between the MDBS **238a** and the mobile terminal **234a** may be, for example, but not limited to, a wireless connection, a wireline connection, and/or an input/output bus interface that may facilitate the exchange of information between devices.

Although **FIG. 2** illustrates an exemplary CDPD communication network **232** architecture, it will be understood that the present invention is not limited to such a configuration, but is intended to encompass any configuration capable of carrying out the operations described herein.

FIG. 3 illustrates a mobile terminal **352** that may be used in embodiments of the mobile terminals **234a,b** of **FIG. 2**, in accordance with the present invention. The mobile terminal **352**, in accordance with embodiments of the present invention, comprises a keyboard/keypad **354**, a display **356**, a transceiver **358**, a memory **362**, a microphone **364**, and a speaker **366** that communicate with a processor **368**. The transceiver **358** typically comprises a transmitter circuit **372**, a receiver circuit **374**, and a modem **376**, which cooperate to transmit and receive radio frequency signals to MDBSs via an antenna **378**. The radio frequency signals transmitted between the

mobile terminal 352 and the MDBSs may comprise both traffic and control signals (e.g., paging signals/messages for incoming calls), which are used to establish and maintain communication with another party or destination. The radio frequency signals may also comprise CDPD packet data.

- 5 The foregoing components of the mobile terminal 352 may be included in many conventional CDPD mobile terminals/end stations and their functionality is generally known to those skilled in the art.

- FIG. 4 illustrates a processor 402 and a memory 404 that may be used in
embodiments of the mobile terminal 352 of FIG. 3 in accordance with the present
10 invention. The processor 402 communicates with the memory 404 via an address/data bus 406. The processor 402 may be, for example, a commercially available or custom microprocessor. The memory 404 is representative of the overall hierarchy of memory devices containing the software and data used to determine the location of a mobile terminal based on the strengths of received signals in accordance with
15 embodiments of the present invention. The memory 404 may include, but is not limited to, the following types of devices: cache, ROM, PROM, EPROM, EEPROM, flash, SRAM, and DRAM.

- As shown in FIG. 4, the memory 404 may have stored thereon an operating system 408, a CDPD protocol stack program module 412, a terminal locator signal
20 strength analysis program module 414, and a data module 416. The operating system 408 generally controls the operation of the mobile terminal's software and/or hardware resources and may coordinate execution of programs by the processor 402. The CDPD protocol stack module 412 may be configured to facilitate communication with MDBSs using the CDPD protocol. The terminal locator signal strength analysis
25 module 414 may be configured to cooperate with the modem 376 (see FIG. 3) to obtain signal strength measurements for signals received from multiple MDBSs. These signal strength measurements may be stored in the data module 416.

- Optionally, the data module 416 may be further configured to store the transmit power levels and the locations of MDBSs from which signals may be
30 received and signal strength measurements may be obtained. For example, the MDBSs may transmit location coordinates and/or transmission power levels to the mobile terminal for storage thereat using, for example, the CDPD protocol. In

accordance with some embodiments of the present invention, the terminal locator signal strength analysis module **414** may use algorithms to determine distances between the mobile terminal and the MDBSs for which signal strength measurements are obtained based on the known transmit power levels of the MDBSs and the obtained signal strength measurements. Other algorithms may then be used to determine a location of the mobile terminal based on the determined distances and the known locations of the MDBSs.

Although **FIG. 4** illustrates an exemplary mobile terminal software architecture that may facilitate determining the location of a mobile terminal based on the strengths of received signals in accordance with embodiments of the present invention, it will be understood that the present invention is not limited to such a configuration but is intended to encompass any configuration capable of carrying out operations described herein.

Computer program code for carrying out operations of the respective mobile terminal program modules may be written in a high-level programming language, such as C or C++, for development convenience. In addition, computer program code for carrying out operations of the present invention may also be written in other programming languages, such as, but not limited to, interpreted languages. Some modules or routines may be written in assembly language or even micro-code to enhance performance and/or memory usage. It will be further appreciated that the functionality of any or all of the program modules may also be implemented using discrete hardware components, one or more application specific integrated circuits (ASICs), or a programmed digital signal processor or microcontroller.

FIG. 5 illustrates a terminal locator data processing system **512** that may be used in embodiments of the terminal locator data processing system **242** of **FIG. 2**, in accordance with the present invention. The terminal locator data processing system **512**, in accordance with embodiments of the present invention, comprises input device(s) **514**, such as a keyboard or keypad, a display **516**, and a memory **518** that communicate with a processor **522**. The terminal locator data processing system **512** may further include a storage system **524**, a speaker **526**, and an input/output (I/O) data port(s) **528** that also communicate with the processor **522**. The storage system **524** may include removable and/or fixed media, such as floppy disks, ZIP drives, hard disks, or the like, as well as virtual storage, such as a RAMDISK. The I/O data port(s)

528 may be used to transfer information between the terminal locator data processing system 512 and another computer system or a network (e.g., the Internet) using, for example, but not limited to, wireless, wireline, and/or communication bus technology. These terminal locator data processing system 512 components may be conventional components, such as those used in many conventional computing devices and/or systems, which may be configured to operate as described herein.

FIG. 6 illustrates a processor 642 and a memory 644 that may be used in embodiments of the terminal locator data processing system 512 of FIG. 5 in accordance with the present invention. The processor 642 communicates with the memory 644 via an address/data bus 646. The processor 642 may be, for example, a commercially available or custom microprocessor. The memory 644 is representative of the overall hierarchy of memory devices containing the software and data used to determine the location of a mobile terminal based on the strengths of received signals in accordance with embodiments of the present invention. The memory 644 may include, but is not limited to, the following types of devices: cache, ROM, PROM, EPROM, EEPROM, flash, SRAM, and DRAM.

As shown in FIG. 6, the memory 644 may have stored thereon an operating system 648, a terminal locator signal strength analysis program module 652, and a data module 654. The operating system 648 generally controls the operation of the computer system. In particular, the operating system 648 may manage the computer system's resources and may coordinate execution of programs by the processor 642. The terminal locator signal strength analysis module 652 may be configured to receive signal strength measurements from a mobile terminal directly and/or indirectly through, for example, one or more MDBSs. These signal strength measurements may be obtained based on CDPD signals received by the mobile terminal from multiple MDBSs as discussed above. Once the mobile terminal signal strength measurements are received at the data processing system, they may be stored in the data module 654.

The data module 416 may be further configured to store the transmit power levels and the locations of MDBSs from which signals may be received and signal strength measurements may be obtained. For example, the MDBSs may transmit location coordinates and/or transmission power levels to the terminal locator data processing system for storage thereat using, for example, the CDPD protocol. Like

the terminal locator signal strength analysis module **414** discussed above with reference to **FIG. 4**, the terminal locator signal strength analysis module **652** may use algorithms to determine distances between the mobile terminal and the MDBSs for which signal strength measurements are obtained based on the known transmit power levels of the MDBSs and the obtained signal strength measurements, in accordance with embodiments of the present invention. Other algorithms may then be used to determine a location of the mobile terminal based on the determined distances and the known locations of the MDBSs.

Although **FIG. 6** illustrates an exemplary data processing system software architecture that may facilitate determining the location of a mobile terminal based on the strengths of received signals in accordance with embodiments of the present invention, it will be understood that the present invention is not limited to such a configuration but is intended to encompass any configuration capable of carrying out operations described herein.

Computer program code for carrying out operations of the respective data processing system program modules may be written in a high-level programming language, such as C or C++, for development convenience. In addition, computer program code for carrying out operations of the present invention may also be written in other programming languages, such as, but not limited to, interpreted languages.

Some modules or routines may be written in assembly language or even micro-code to enhance performance and/or memory usage. It will be further appreciated that the functionality of any or all of the program modules may also be implemented using discrete hardware components, one or more application specific integrated circuits (ASICs), or a programmed digital signal processor or microcontroller.

The present invention is described hereinafter with reference to flowchart and/or block diagram illustrations of methods, systems, and computer program products in accordance with exemplary embodiments of the invention. It will be understood that each block of the flowchart and/or block diagram illustrations, and combinations of blocks in the flowchart and/or block diagram illustrations, may be implemented by computer program instructions and/or hardware operations. These computer program instructions may be provided to a processor of a general purpose computer, a special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the

processor of the computer or other programmable data processing apparatus, create means for implementing the functions specified in the flowchart and/or block diagram block or blocks.

These computer program instructions may also be stored in a computer usable
5 or computer-readable memory that may direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer usable or computer-readable memory produce an article of manufacture including instructions that implement the function specified in the flowchart and/or block diagram block or blocks.

10 The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions that execute on the computer or other programmable apparatus provide steps for implementing the functions
15 specified in the flowchart and/or block diagram block or blocks.

Referring now to **FIG. 7**, operations begin at block **762** where a mobile terminal receives signals (*e.g.*, CDPD signals) from multiple transmitters, such as MDBSs. At block **764**, the modem **376** in the mobile terminal measures the signal strengths of the received signals and provides the signal strengths to the terminal
20 locator signal strength analysis module **414** (see **FIG. 4**). Based on these measured signal strengths, the terminal locator signal strength analysis module **414** determines the distances between the mobile terminal and the transmitters at block **766** based on the measured signal strengths and the power levels of the transmitters, which may be stored in the data module **416**. The terminal locator signal strength analysis module
25 **414** may then determine the location of the mobile terminal based on the determined distances and the known locations of the multiple transmitters, which may be stored in the data module **416**, as discussed above with reference to **FIG. 4**.

In accordance with preferred embodiments of the present invention, the mobile terminal obtains signal strength measurements for signals received from at least three
30 transmitters having different locations. For example, referring now to **FIG. 2**, the mobile terminal **234a** may scan CDPD channels transmitted from MDBSs in its own cell and cells adjacent thereto, *e.g.*, MDBSs **238a,b,d** in cells **236a,b,d**, respectively, to obtain signal strength measurements. Alternatively, to obtain as many

measurements as possible for improved location accuracy, the mobile terminal **234a** may scan channels from more than three transmitters, including CDPD channels transmitted from MDBSs that are located in cells that are not adjacent to cell **236a**, such as MDBS **238c** in cell **236c**.

5 In other embodiments of the present invention, the location of the mobile terminal need not be determined by the mobile terminal. Instead, the terminal locator signal strength analysis module **414** of the mobile terminal may transmit the measured signal strengths of the received signals to a data processing system, such as the terminal locator data processing system **242** of **FIG. 2**. Based on these measured
10 signal strengths, the terminal locator signal strength analysis module **652** (see **FIG. 6**) of the data processing system determines the distances between the mobile terminal and the transmitters based on the measured signal strengths and the power levels of the transmitters, which may be stored in the data module **654**. The terminal locator signal strength analysis module **652** may then determine the location of the mobile
15 terminal based on the determined distances and the known locations of the multiple transmitters, which may be stored in the data module **654**, as discussed above with reference to **FIG. 6**. Once the location is determined, it may be communicated back to the mobile terminal.

Advantageously, the present invention may allow the location of a mobile
20 terminal to be determined with greater accuracy than just an identification of a particular cell location. The accuracy achieved is related, however, to the accuracy of the signal strength measurements.

The flowchart of **FIG. 7** illustrates the architecture, functionality, and operations of embodiments of the mobile terminal **352** and the terminal locator data processing system **512** software. In this regard, each block represents a module,
25 segment, or portion of code, which comprises one or more executable instructions for implementing the specified logical function(s). It should also be noted that in some alternative implementations, the function(s) noted in the blocks may occur out of the order noted in **FIG. 7**. For example, two blocks shown in succession may, in fact, be
30 executed substantially concurrently or the blocks may sometimes be executed in the reverse order, depending on the functionality involved.

An exemplary methodology for determining a location of a mobile terminal, in accordance with embodiments of the present invention, will now be described with

reference to **FIG. 8**. A mobile terminal at position (x, y) is located a distance R_1 from a first transmitter at position (x_1, y_1) , a distance R_2 from a second transmitter at position (x_2, y_2) , and a distance R_3 from a third transmitter at position (x_3, y_3) . The relationship between received signal strength indication ($RSSI$), transmit power P , and distance R from a transmitter may be given by Equation 1:

$$RSSI \propto \frac{P}{R^2} \quad \text{EQ. 1}$$

Equation 1 can be rewritten as Equation 2 below:

$$R^2 = k \frac{P}{RSSI} \quad \text{EQ. 2}$$

where k is a constant. Applying Equation 2 to the network schematic of **FIG. 8** allows the distances R_1 , R_2 , and R_3 , to be given by Equations 3 through 5:

$$R_1^2 = k \frac{P_1}{RSSI_1} \quad \text{EQ. 3}$$

$$R_2^2 = k \frac{P_2}{RSSI_2} \quad \text{EQ. 4}$$

$$R_3^2 = k \frac{P_3}{RSSI_3} \quad \text{EQ. 5}$$

If $P_1 = 2.5\text{W}$, $RSSI_1 = 10^{-9}\text{W}$, $P_2 = 9\text{W}$, $RSSI_2 = 10^{-8}\text{W}$, $P_3 = 3.6\text{W}$, $RSSI_3 = 10^{-9}\text{W}$, and $k = 10^{-4}\text{m}^2$, then, using Equations 3 through 5, $R_1 = 500\text{m}$, $R_2 = 300\text{m}$, and $R_3 = 600\text{m}$.

The relationship between the distances R_1 , R_2 , and R_3 , is given by Equations 6 through 8 as follows:

$$R_1^2 = (x - x_1)^2 + (y - y_1)^2 \quad \text{EQ. 6}$$

$$R_2^2 = (x - x_2)^2 + (y - y_2)^2 \quad \text{EQ. 7}$$

$$R_3^2 = (x - x_3)^2 + (y - y_3)^2 \quad \text{EQ. 8}$$

If $R_1 = 500\text{m}$, $x_1 = 100\text{m}$, $y_1 = 100\text{m}$, $R_2 = 300\text{m}$, $x_2 = 400\text{m}$, $y_2 = 800\text{m}$, $R_3 = 600\text{m}$, $x_3 = 1000\text{m}$, and $y_3 = 500\text{m}$, then, using Equations 6 through 8, $x = 400\text{m}$ and $y = 500\text{m}$.

Many variations and modifications can be made to the preferred embodiments without substantially departing from the principles of the present invention. All such variations and modifications are intended to be included herein within the scope of the present invention, as set forth in the following claims.